Technical Paper 50

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METALLURGICAL COKE

BY

A. W. BELDEN

WASHINGTON
GOVERNMENT PRINTING OFFICE
1913

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METALLURGICAL COKE.

By A. W. Belden.

INTRODUCTION AND ACKNOWLEDGMENTS.

In this paper the attempt is made to summarize the history of coke making in the United States, to indicate the development of different methods and the modern types of ovens, and to point out the composition and physical properties of the metallurgical cokes produced in this country. The paper is issued by the Bureau of Mines as one of a series of fuel-technology publications that has for its purpose the presentation of information regarding methods by which mineral fuels belonging to or for the use of the United States may be used more efficiently. In the preparation of this paper many sources of information have been drawn upon, for which due acknowledgment is made in the text. The illustrations, other than those made by the author, are from articles that have appeared from time to time in technical papers and from manufacturers' and operators' announcements and catalogues. Especial acknowledgment is due the Iron Age, Coal Age, Iron Trades Review, United Coke & Gas Co., and to pamphlets issued by the makers of the Koppers coke oven and by the Harbison-Walker Refractories Co.

HISTORY OF COKE MAKING IN THE UNITED STATES.

From an examination of available data the author summarizes the history of the establishment and progress of coke making in the United States as follows:

In 1817 coke "made on the ground" was used in the rolling mill of Col. Isaac Meason, at Plumcock, Fayette County, Pa. Two years later a blast furnace was erected near Lawrenceburg, Pa., for the use of coke, but owing to the weakness of the blast and other causes the furnace was not successful and ceased operations after making a ton or two of iron. From that time until 1825 no mention of the use of coke can be found, though the many histories, reports, and papers examined show that the subject received much attention. No doubt many experiments were made in the use of coke alone and

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in mixtures with charcoal, anthracite, and bituminous coal. In 1825 William Strickland, who was sent to England by the Pennsylvania Society for the Promotion of Internal Improvement, forwarded a report of his investigations of the methods employed in the manufacture of iron, in which detailed plans of ovens used for making coke were submitted. This report of Mr. Strickland undoubtedly stimulated experiments in the use of coke, and the records of 1836–37 show that iron was made in furnaces using coke alone as fuel. No record of any coke made in ovens can be found, though it is probable that some experiments with ovens were made, based on the information obtained by Mr. Strickland.

The first authentic record of the use of ovens for making coke appears in the year 1841, when Provance McCormick, James Campbell, and John Taylor formed a partnership for the manufacture and sale of coke made in two ovens on Taylor's farm. In the report of the late J. D. Weeks on The Manufacture of Coke in the United States in the Census Year 1880 the following account of the venture, as related by McCormick, is given:

James Campbell and myself heard in some way that I do not now recollect that the manufacturing of coke might be made a good business. Mr. John Taylor, a stone mason, who owned the farm on which the Fayette coke works now stand, and who was mining coal in a small way, was spoken to regarding our enterprise, and proposed a partnership—he to build the ovens and make the coke and Mr. Campbell and myself to build a boat and take the coke to Cincinnati, where we heard there was a good demand. This was in 1841. Mr. Taylor built two ovens. I think they were about 10 feet in diameter. My recollection is that the charge was 80 bushels. The ovens were built in the same style as those now used, but had no iron ring at the top to prevent the brick from falling in when filling the oven with coal, nor had we any iron frames at the mouth where the coke was drawn. The top and mouth had to be repaired when they fell in. In the spring of 1842 enough coke had been made to fill two boats 90 feet long—about 800 bushels each—and we took them to Cincinnati, down the Youghiogheny, Monongahela, and Ohio, but when we got there we could not sell. Mr. Campbell, who went with the boats, lay at the landing some two or three weeks, retailing out one boatload and part of the other in small lots at about 8 cents a bushel. Miles Greenwood, a foundryman of that city, offered to take the balance if he would take a small patent flour mill at $125 in pay, which Mr. Campbell did. He had it shipped here. We tried it, but it was no good, and we sold it to a man in the mountains for $30, and thus ended our coke business.

The use of this coke proved to be so successful that the partners were requested to continue its manufacture and were guaranteed a sale for all they could deliver at Cincinnati at 8 cents a bushel, but they were so disgusted with their venture that they refused to have anything more to do with coke.

From 1841 until 1855 a few ovens were built and some experiments were made. In 1855 it is stated that there were only 26 coke ovens along the river above Pittsburgh. On the completion of the Clinton

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furnace of Graff, Bennet & Co., at Pittsburgh, in 1859, the successful use of coke as a blast-furnace fuel was thoroughly demonstrated and 30 ovens were built at the Fayette coke works. From that time coke manufacture increased by leaps and bounds in all sections of the country, and by 1911 there were 103,879 ovens, in 24 different States.

STATISTICS OF PRODUCTION.

The following tables, published by the United States Geological Survey in "Mineral Resources of the United States, 1911," show the growth of the coking industry from 1880 to 1911:

TABLE 1.—*Growth of the coke industry (1880–1911).*

Year.	Number of establishments.	Number of ovens.		Coal used.	Coke produced.	Yield of coal in coke.
		Built.	Building.			
				Short tons.	*Short tons.*	*Per cent.*
1880	186	12,372	1,159	5,237,741	3,338,300	63.0
1890	253	37,158	1,547	18,005,209	11,508,021	64.0
1900	396	58,484	5,804	32,113,543	20,533,348	63.9
1901	423	63,951	5,205	34,207,965	21,795,883	63.7
1902	456	69,069	8,758	39,604,007	25,401,730	64.1
1903	500	79,334	6,175	39,423,525	25,274,281	64.1
1904	506	83,599	4,430	36,531,608	23,661,106	64.8
1905	519	87,564	4,751	49,530,677	32,231,129	65.1
1906	532	93,901	4,519	55,746,374	36,401,217	65.3
1907	552	99,680	2,546	61,946,109	40,779,564	65.8
1908	551	101,218	2,241	39,440,837	26,033,518	66.0
1909	579	103,982	2,950	59,354,937	39,315,065	66.2
1910	578	104,440	2,567	63,088,327	41,708,810	66.1
1911	570	103,879	2,254	53,278,248	35,551,489	66.7

TABLE 2.—*Number of coke ovens, by States, 1911.*

State.	Number of beehive ovens.		Number of by-product ovens.		Total number of ovens.	
	Built.	Building.	Built.	Building.	Built.	Building.
Alabama	9,781	0	340	280	10,121	280
Colorado	3,606	0	0	0	3,606	0
Georgia	225	0	0	0	225	0
Illinois	26	0	480	48	506	48
Indiana	46	22	540	70	586	92
Kansas	53	0	0	0	53	0
Kentucky	577	300	0	0	577	300
Maryland	0	0	200	0	200	0
Massachusetts	0	0	400	0	400	0
Michigan	0	0	162	0	162	0
Minnesota	0	0	50	0	50	0
Montana	451	3	0	0	451	3
New Jersey	0	0	150	0	150	0
New Mexico	1,030	0	0	0	1,030	0
New York	0	0	556	0	556	0
Ohio	322	0	174	0	496	0
Oklahoma	410	0	0	0	410	0
Pennsylvania	53,612	971	1,292	300	54,904	1,271
Tennessee	2,547	30	0	0	2,547	30
Utah	854	0	0	0	854	0
Virginia	5,496	100	0	0	5,496	100
Washington	235	0	0	0	235	0
West Virginia	19,756	130	120	0	19,876	130
Wisconsin	228	0	160	0	388	0

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From 1893, when the first plant of 12 by-product ovens was completed by the Semet-Solvay Co., of Syracuse, N. Y., to the close of 1911 there was a steady and noteworthy increase in the construction of by-product ovens in the United States. At the end of 1911 there were 4,624 by-product ovens, using 10,446,584 tons of coal and producing 7,847,845 tons of coke, a yield of 75.1 per cent. The growth of by-product coke making is shown in the following table:

TABLE 3.—*Growth of by-product coke making (1893–1911).*

Year.	Number of ovens.		Coal used.	Coke produced.	Yield of coal in coke.
	Built.	Building.			
			Short tons.	*Short tons.*	*Per cent.*
1893	12			12,850	
1894	12	60		16,500	
1895	72	60		18,521	
1896	160	120		83,038	
1897	280	240		261,912	
1898	520	500		294,445	
1899	1,020	65		906,534	
1900	1,085	1,096		1,075,727	
1901	1,165	1,533		1,179,900	
1902	1,663	1,346		1,403,588	
1903	1,956	1,335		1,882,394	
1904	2,910	832	3,572,916	2,608,229	73
1905	3,103	417	4,628,891	3,462,348	74.8
1906	3,547	112	6,193,107	4,558,127	73.6
1907	3,684	330	7,506,174	5,607,899	75
1908	3,799	240	5,699,058	4,201,226	73.7
1909	3,989	949	8,390,129	6,254,644	74.5
1910	4,078	1,200	9,529,042	7,138,734	74.9
1911	4,624	698	10,446,584	7,847,845	75.1

DEVELOPMENT OF COKING METHODS.

The chief object of coking is to obtain, from any given coal, the maximum amount of good metallurgical coke at the least consumption of the fixed carbon of the coal. This end has been attained in progressive ratio, from the earliest methods of coking in mounds or piles to the modern by-product oven, the beehive oven, with its various improvements, being the intermediate stage.

COKING IN MOUNDS OR PILES.

Coking in mounds or piles is no longer done in this country. Reports show that the coke made in this way was an excellent fuel, although it lacked uniformity. The yield was small because the method of manufacture, which undoubtedly had its inception in charcoal burning, was necessarily wasteful. It reached its highest perfection in this country through the Cambria Iron Co. in the Allegheny Mountain region of Pennsylvania. The following description of the method of coking in mounds or piles, as well as the illustration here shown (fig. 1), are taken from Report L of the Second Pennsylvania Geological Survey, page 122:

The coke yard is prepared by leveling a piece of ground and surfacing it with coal dust. The coal to be coked is then arranged in heaps or pits, with longitudinal transverse and vertical flues, sufficient wood being distributed in these

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to ignite the whole mass. Beginning on a base 14 feet wide, the coal is spread to a depth of 18 inches, as in A. On this base the flues are arranged and constructed as shown in the plan, the coal being piled up, as shown in section B. These flues are made of refuse coke and lump coal, and are covered with billets of wood. When the heap is ready for coking, fire is applied at the base of vertical flues, C, C, igniting the kindling wood at each alternate flue. As the process advances the fire extends in every direction, until the whole mass is ablaze. Considerable attention is required in managing this mode of coking in diffusing the fire evenly through the mass, in preventing the waste of coke by too much air at any place, and in banking up the heaps with fine dust as the operation progresses from base to top. When the burning of the gaseous matter has ceased the heap is carefully closed with dust or "duff" and nearly smothered out in this way. The final operation is the application of a small quantity of water down the vertical flues, which is quickly converted into steam, permeating the whole mass. This gives coke, if carefully applied, the least percentage of moisture. The time necessary for coking a heap with the Bennington coal is from five to eight days, depending mainly on the state of the weather.

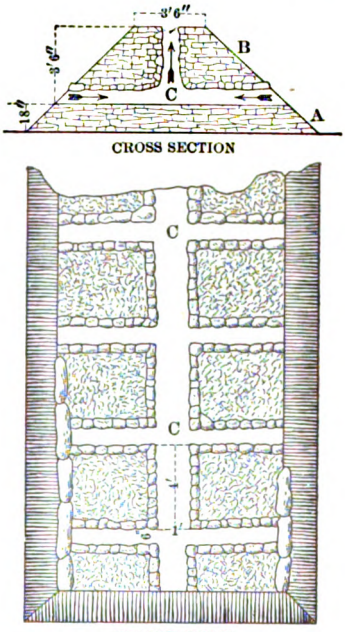

FIGURE 1.—Coke mound or pile.

YIELD OF COKE.

The yield of coke in the above process at Bennington yard is given as 59.1 per cent. It is not stated whether this is the total yield, the sum of the percentages of coke, breeze, and ashes, or the yield of good coke. No analysis of coal or coke is given. This record, as well as one showing the percentage of coke obtained at Hollidaysburg yard to be 59.6, are undoubtedly due to the extra precautions taken to insure the best possible results and do not represent the actual average yield from this method of coking. A yield of 50 to 55 per cent would probably more nearly represent the average proportion of good coke by the process of coking in mounds or piles as compared with a yield of 60 to 65 per cent from the same coal in beehive ovens.

COKING IN BEEHIVE OVENS.

FEATURES OF THE OVEN.

The essential features of the beehive oven are a circular, vaulted fire-brick chamber constructed on a suitable foundation, with flat tile bottom, an opening in the top through which the coal is charged and the products of combustion escape, and an arched door at the bottom

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about 3 feet high, through which the air for combustion is admitted and the coke is watered and drawn. The many variations and improvements since the 10-foot diameter oven of McCormick, Campbell & Taylor have resulted in the present standard beehive oven (fig. 2). The size of the door, "the trunnel head," the height of the dome, and the diameter of the oven vary in different localities, but the essential features are the same. Ovens are built in single rows called bank ovens (fig. 3), or in double rows back to back or staggered (fig. 4).

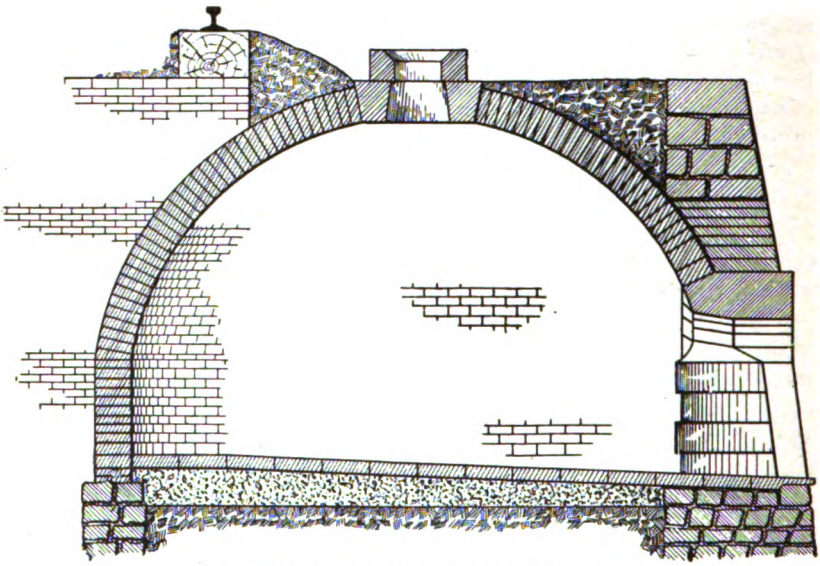

FIGURE 2.—Section of standard beehive oven.

BEEHIVE OVENS FOR MECHANICAL DRAWING OF COKE.

The beehive oven for mechanical drawing of coke differs from the oven described above only in the width of the door and in the protecting iron jambs at the bottom of the door. Figure 5 shows one form of coke-drawing machine.

Mechanical drawing of coke from beehive ovens has been adopted on account of the scarcity, and hence the cost, of labor, and not because of any increase in efficiency resulting from the use of machinery. It is even doubtful whether mechanical drawing causes a material reduction in the cost of operation if all items are taken into consideration. Mechanical drawing reduces the time of drawing decidedly but it also undoubtedly breaks up the coke more, producing a large percentage of breeze. The enlarged size of the door makes the regulation of draft more difficult and causes much burned coke. The practice of watering long in advance of drawing, especially when the precaution of putting the lid on the "trunnel head" is not followed, causes a

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rapid cooling of the oven and reduces the percentage of coke obtained by increasing the length of time necessary for the next charge to ignite. This either increases the time required for burning the same size charge or necessitates the reduction of the size of the charge if it is desired to burn down the ovens on time.

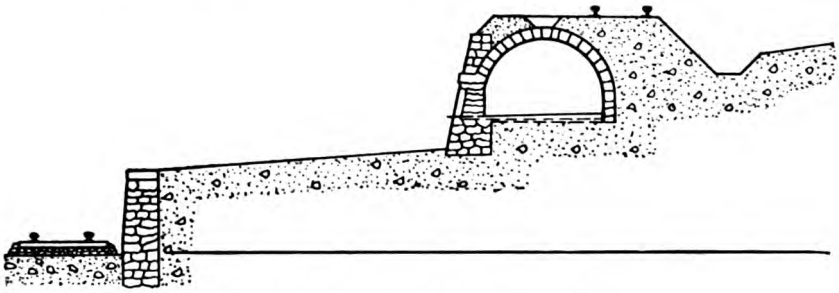

FIGURE 3.—Section of beehive bank ovens.

MECHANICAL LEVELING OF BEEHIVE OVENS.

A patented machine (fig. 6) for mechanically leveling coal in beehive ovens has recently been put on the market and is now in operation in the Connellsville coke region. It gives evidence of proving its usefulness not only by eliminating labor, but by encouraging the proper leveling of ovens, an operation often neglected or considered of little concern. The proper leveling of coal in any oven is really a matter of great importance, and it is to be regretted that operators of beehive ovens throughout the country pay so little attention to this feature of coke making. Either through ignorance or neglect on the

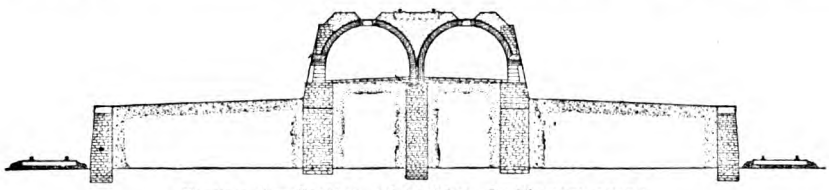

FIGURE 4.—Section of beehive double-row ovens.

part of superintendents and other officials, this detail of coke making is mostly left to levelers who are not properly trained to the work and who, being paid by the oven, naturally desire to level as many ovens of coke in a day as possible. Improper leveling causes the different heights of charge to coke to the bottom in different periods of time, with the result that the top surface of the coke is exposed to the action of the air admitted for the completion of the process, and some coke is burned and lost. On the other hand, if the process be stopped short of completion, blackbutts or partly coked coal will be found in the coke from the higher portions of the charge.

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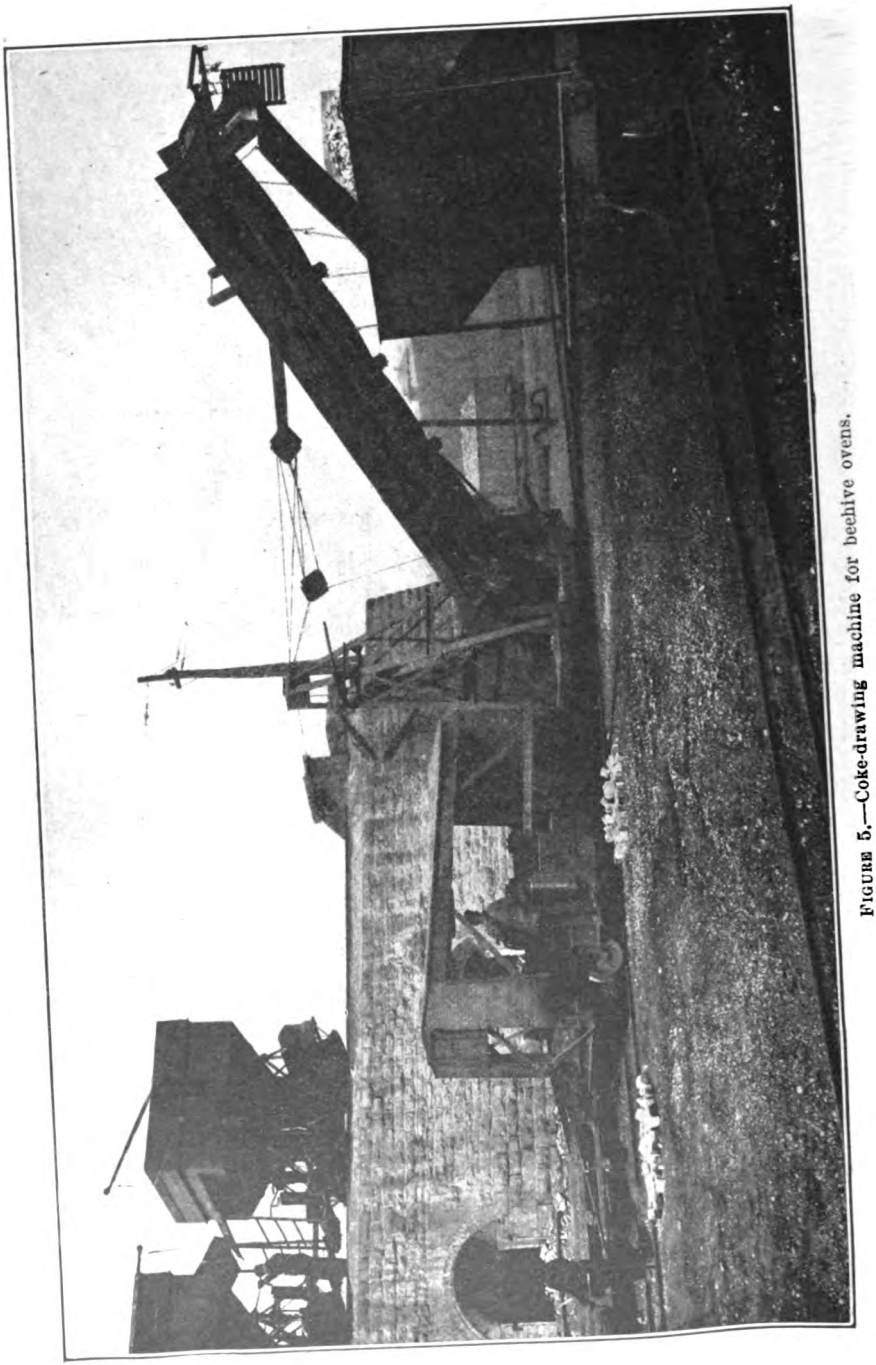

FIGURE 5.—Coke-drawing machine for beehive ovens.

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STARTING A BLOCK OF OVENS.

On starting a block of ovens a fire of wood and coal is built and the door bricked up and daubed with loam, leaving a bottom draft for quick burning of the coal. After the ovens are heated for a time, depending on the amount of heat absorbed by the fire brick, the door of each oven is torn down and the oven thoroughly cleaned. The door is then bricked up to a point where the leveler can conveniently handle his scraper and a small charge of coal is put in through the "trunnel

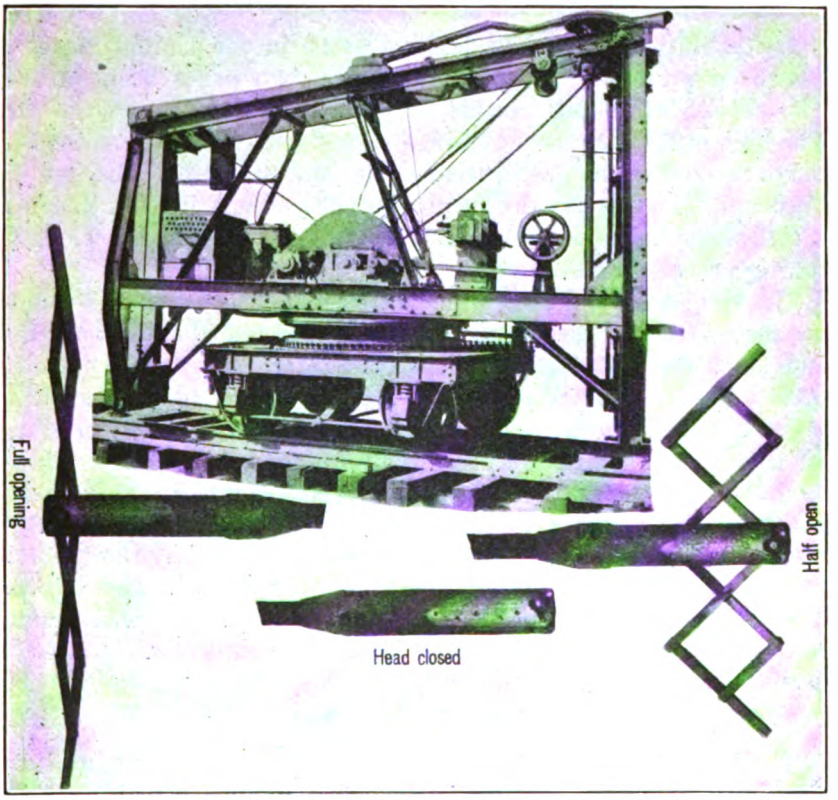

FIGURE 6.—Leveling machine for beehive oven.

head." After one or two burnings with small charges the oven is in shape for continuous work.

CHARGING A BEEHIVE OVEN.

An amount of coal, determined according to whether the oven is to be burned 48 or 72 hours, is charged into the oven from a car, or larry, running on a track above the oven. The coal in falling into the oven forms a conical pile which is leveled by means of a scraper. The door is then bricked up to 2 or 3 inches of the top. The heat

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from the previous charge, held by the brick, raises the temperature to the point where the volatile matter distilled from the coal finally ignites. The coking proceeds from the top downward, and in order to maintain the highest heat the burning of the volatile matter is regulated by closing up the air opening as the proportion of volatile decreases. After the volatile matter has ceased to come off the process is done; the door is torn down, and the coke is sprayed with water and is drawn from the oven.

NEED OF SCIENTIFIC METHODS.

The evolution of modern beehive ovens in the United States, as shown in preceding pages, started with two ovens built in 1841. The process of coking has not been materially changed since then. The higher efficiency now obtained is due chiefly to improvements in the ovens and in the preparation of the coal before it is charged into the ovens. To this day the burning of coke, except in a few instances, is left in the hands of unskilled laborers, and technical knowledge of coking processes is woefully lacking.

The strides made in the iron and steel industries of this country are the wonder of the world. The highest technical skill is procured and much study and thought are constantly given to the improvement of details. Back of this progress and directly responsible for it is the fuel necessary for the furnaces, cupolas, and other metallurgical uses. Yet until 1896, when the by-product coking industry began to grow appreciably, little was heard of any technical study or deep thought being applied to coke making. The determination of the coking properties of any coal was generally decided by the report of practical coke burners from the Connellsville region. The very fact that Connellsville coal produces coke of excellent quality, no matter how inefficiently the ovens are handled, should preclude the use of such evidence.

LOSS OF COKE BY BURNING.

The handling of the modern beehive oven, as practiced in all sections of the country, undoubtedly gives a lower yield of coke than might be obtained, but the matter of increased yield, even when brought to the attention of those in authority, is most often passed over with the remark, "We are doing well enough and making money, so why should we make any change?" One reason why it is so hard to impress the importance of greater efficiency on the mind of the coke manufacturer is that he does not know what yield he is getting. He is satisfied to use figures that show the amount of coke produced if they come anywhere near what he thinks he ought to obtain. The 1911 returns to the division of mineral statistics of the

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United States Geological Survey show the average yield of coke in beehive ovens for the country to be 64.7 per cent, but if figures showing the actual tonnages of coal charged and coke produced were obtainable, the yield would probably more nearly approach that in mounds or piles as given above, namely, 59 per cent. There is no doubt that with proper supervision of the burning of coke this figure could be increased 3 to 5 per cent. A conservative estimate of the direct loss from the 27,703,644 tons of coke produced in this country in beehive ovens in 1911 is 1,154,318 tons, worth over $3,266,350. The gratifying increase in by-product coke production, the output being 22.07 per cent of the total production in 1911, shows that the country is waking up to the necessity of curtailing this enormous waste. That the importance of greater efficiency is being appreciated, and that a still more rapid increase in the number of by-product ovens may be expected, are shown by the large number of inquiries now in the hands of the by-product oven builders. The fact that the country's best coking coals are rapidly becoming exhausted makes the scientific study of the process of coking more imperative, and it is only the by-product oven that can give the proper answer to the many questions asked.

LONGITUDINAL OVENS.

The scarcity of labor, the use of unskilled labor, and the higher cost of coking coal have led to experiments to offset these three factors, first by making the coking operation independent of large forces of laborers and second by decreasing the actual cost of operation. In 1906 the longitudinal oven (a modification of the old Belgian oven), with its mechanical devices for leveling, pushing, and loading coke, was evolved from these experiments. The essential features of the longitudinal oven are a long, narrow, rectangular chamber, generally somewhat larger at the discharging end, with a flat tile bottom, a sloping barrel roof approaching from both ends, a trunnel head in the center of the roof, and doors the whole width of the chamber at either end. These ovens, placed side by side, form a block and are charged, as are beehive ovens, from a larry running on a track on top of the ovens. The oven is supplied with air from both ends, after the method of the beehive oven, and the coke, after being watered inside of the oven, is pushed out by means of a special pusher on to a traveling conveyor. This conveyor transfers the coke to cars, screening being more or less fully accomplished during the passage of the coke along the conveyor. A section of an oven showing the method of operation is presented in figure 7. The dimensions of the ovens vary according to the different ideas of the engineers constructing them. Many claims are made for the

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longitudinal oven in regard to increased yield, a better product, and lower cost of operation. The owners and operators of these ovens are enthusiastic and confident of their success, but the more conservative coke operators are withholding their judgment until the

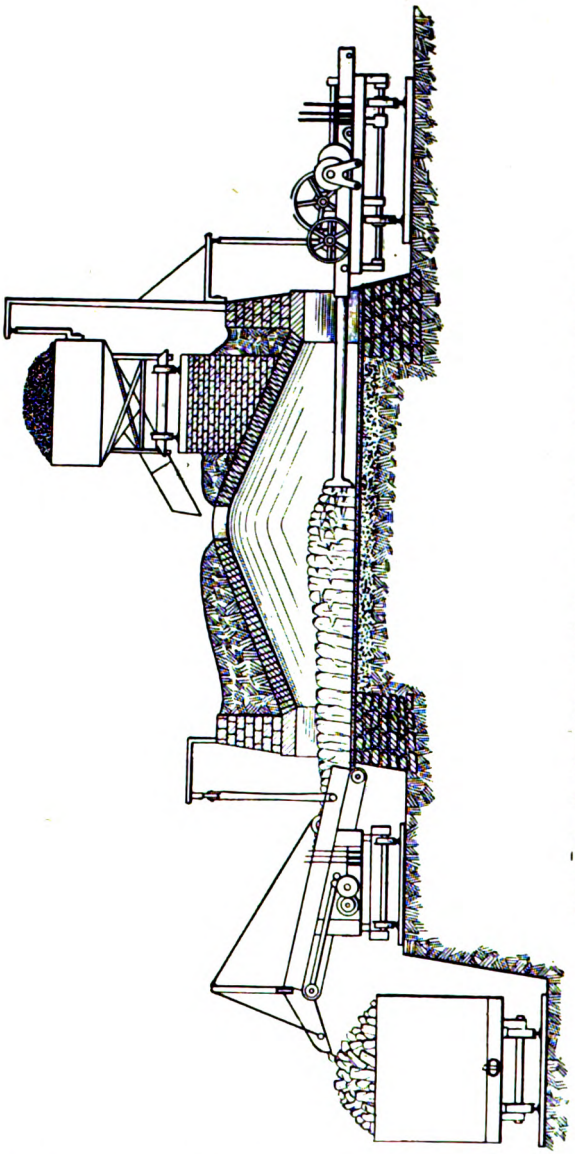

FIGURE 7.—Section of longitudinal oven, showing method of operation.

ovens have been in use for a longer period and have proved their worth by actual demonstration of the many claims made for longitudinal ovens. Figure 8 shows the leveling and pushing apparatus and figure 9 the conveyor used at one of the first plants established.

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REGULATION OF DRAFT IN THE BEEHIVE OVEN.

The draft of the beehive oven should be so regulated that the maximum degree of heat is obtained by burning the volatile matter

FIGURE 8.—Leveling and pushing machine for longitudinal ovens.

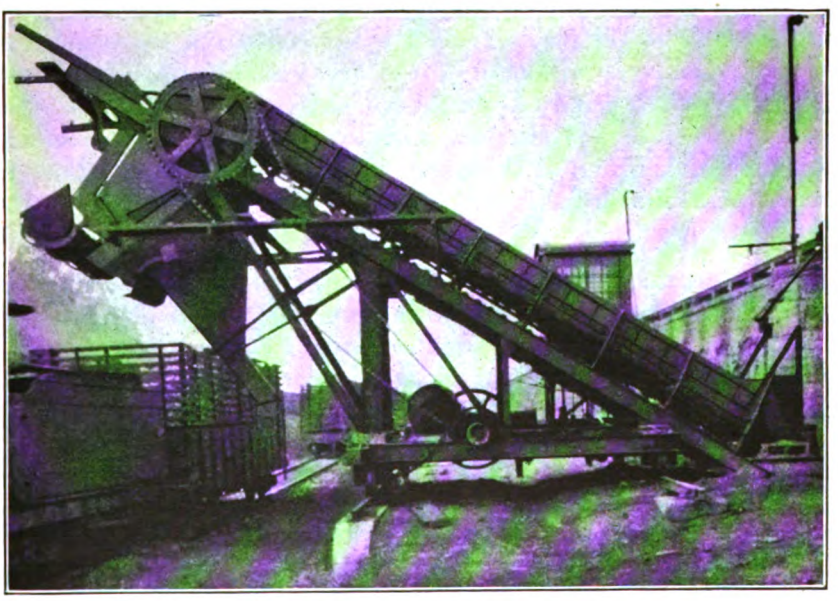

FIGURE 9.—Conveyor for longitudinal ovens.

of the coal at a point above the charge, which prevents burning the fixed carbon of the coal and leaves the oven in proper condition for the next charge. The volume of air admitted should be decreased as the volatile matter decreases. The study of this feature of beehive-

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oven practice shows that it is not receiving proper attention, especially toward the latter part of the coking process. Failure to close the draft at the proper time delays coking at any stage, and during the last few hours of the coking process it results in burning up coke, cooling the whole oven, and putting it in bad condition for the next charge. Subsequent charges have to be materially reduced to get the oven in proper condition again, or blackbutts are produced, because the oven, much delayed in catching up, does not come off at the proper time and the charge is not properly coked to the bottom. Blackbutts are the soft black ends of the coke at the bottom of the prisms and are generally due to a cold or dirty bottom, but may also be produced by improper regulation of the draft during the last part of the coking. In the latter case the process is slowed on account of the decrease in temperature and volatile matter is left in the coke. The use of too large charges, usually in an endeavor to increase the output during prosperous times, always causes blackbutts, and is poor policy, generally defeating the very object for which it is tried. An oven of a given size will, under the most favorable conditions, produce only a certain amount of coke from a given coal, and although the weight of merchantable product drawn may be slightly increased for one or two charges, the reduction of the amount of coal charged subsequently to get the oven back to condition and the amount of breeze carted away will show on the wrong side of the ledger every time. It is much better to find out the maximum amount of coal that can in a given time produce the maximum amount of good coke and the minimum amount of breeze and ashes and then to insist that the output be kept at this figure.

BREEZE.

Breeze, as the term is commonly used, is the waste from the coke oven. The coke after being drawn from the oven is either forked in the case of hand drawing or passed over a conveyor in the case of mechanical drawing, and the breeze is the portion that passes between the tines of the fork in the one instance or through the perforations of the conveyor in the other. The amount of breeze produced is seldom taken into account. Manufacturers as a rule have no check on the coking operations, and therefore do not know the total yield obtainable from their coal. In fact, most reports of coke yield give the possible theoretical yield without taking the breeze and ashes into account.

It is practically impossible to regulate the air admitted to a beehive oven so that fixed carbon will not be burned, and with coals having a low volatile matter content it is absolutely necessary to burn a part of the fixed carbon in order to maintain the heat and finish the coking process. Connellsville coal, with 31 per cent volatile matter, contains just the proper amount and composition of volatile constituents to

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maintain uniformity of heat and to produce in the beehive oven a maximum yield of coke with a minimum loss of fixed carbon. This does not mean that any coal of approximately the same analysis will also produce a maximum yield of coke with a minimum loss of fixed carbon. Many factors of which no knowledge has yet been gained enter into the question; probably the composition of the volatile itself, the temperature at which the volatile is given off, its varying richness and heating power, and other factors will have to be thoroughly examined before we can attempt to make definite answer. A beginning in such inquiries has been made and some interesting data have been obtained as a result of the investigations of the United States Bureau of Mines by Porter and Ovitz [a] and at the laboratory of the British coal dust experiment station by Wheeler and Burgess.[b]

BEEHIVE OVEN WITH ARRANGEMENT FOR UTILIZING WASTE HEAT OF GASES.

Waste heat from beehive ovens is utilized for the generation of steam at a few plants in this country. Figure 10 shows a section of a bank oven and tunnel with connecting flue. Each oven is provided with a tunnel, which in bank ovens is built directly behind the oven and in ovens arranged in double rows is built between the rows, and this tunnel extends the whole length of the ovens to be used for generating steam. From each oven a flue leading from the oven to the tunnel is provided and is so arranged that it can be closed by damper. This flue is built in the crown of the oven above the height to which the coal is charged. Numerous modes of placing this flue have been tried. The usual practice is to use a short straight flue leading from the oven direct to the tunnel. At the boiler end of the tunnel a large stack is built to cause proper draft. The regular tunnel head is covered and kept closed during operation, the gases passing through the flue into the tunnel instead of into the open air as in ordinary

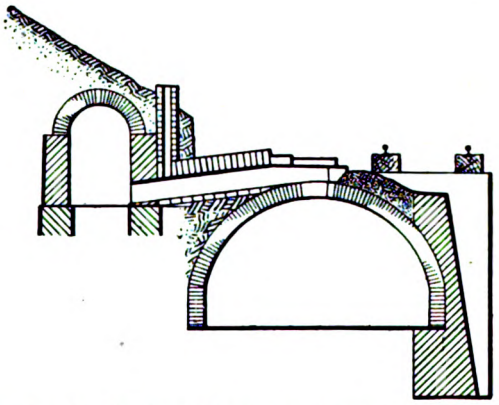

FIGURE 10.—Section of bank oven, tunnel, and connecting flue for waste-heat system.

[a] Porter, H. C., and Ovitz, F. K., The volatile matter of coal: Bull. I, Bureau of Mines, 1910.

[b] Burgess, M. J., and Wheeler, R. V., The volatile constituents of coal: Jour Chem. Soc., vol. 97 (2), 1910, pp. 1917–1935, and vol. 99 (1), 1911, pp. 649–667.

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beehive ovens. The hot gases from the ovens pass along the tunnel, through the boiler setting, and out of the stack. The temperature in the flues is high, approximately 2,700° F., and the building of flues

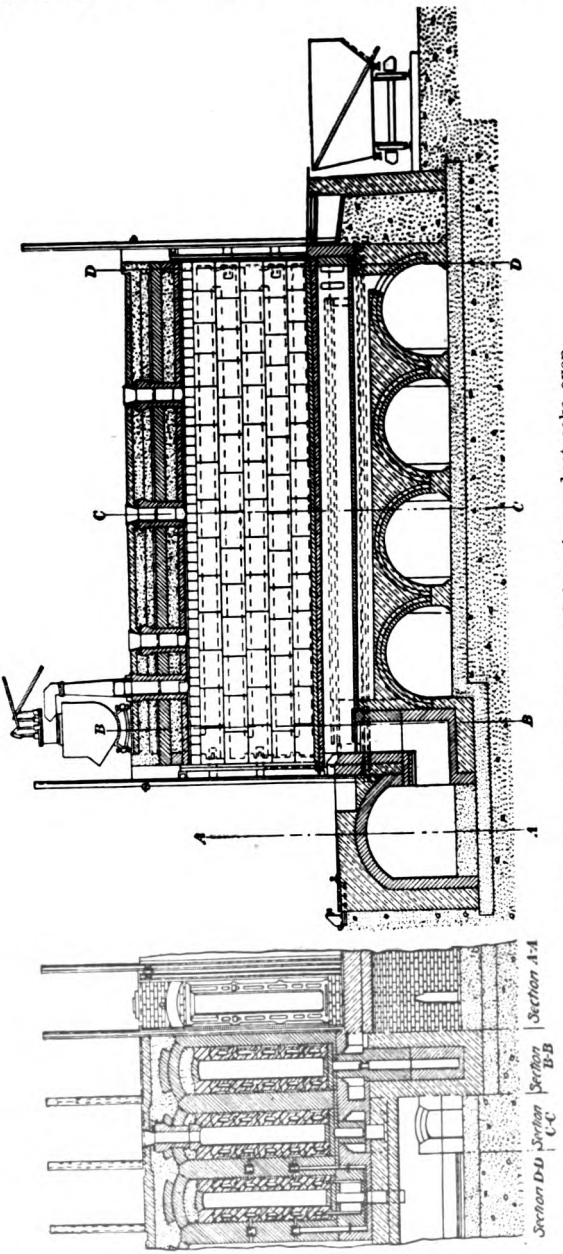

FIGURE 11.—Sections of Semet-Solvay by-product coke oven.

that can withstand such intense heat is a matter of much consequence. The temperature of the gases at the boiler approximates 2,000° F., and the volume of the gases is sufficient in amount to generate 12 to

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20 horsepower per oven. The ovens burn hotter under these conditions than when burning into the air because of the better draft on the ovens.

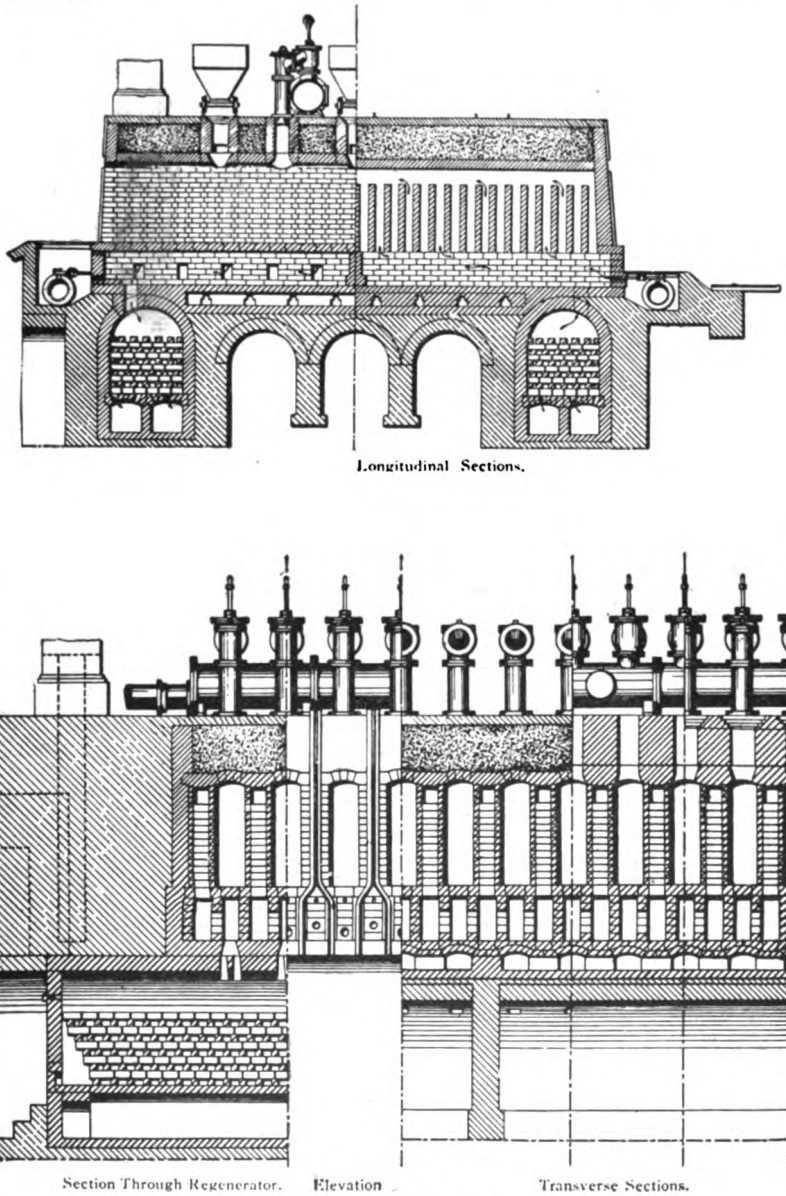

FIGURE 12.—Sections of Otto-Hoffman by-product coke oven.

BY-PRODUCT OVENS.

Sections of the principal types of by-product coke ovens in operation in this country are shown in figures 11, 12, 13, and 14. The

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several designs are based on two general types, which, though varying in detail of construction, are either a modification of the original Coppée (vertical flue), figure 15, or of the Simon-Carves (horizontal flue), figure 16. The coking chamber consists of a long narrow retort

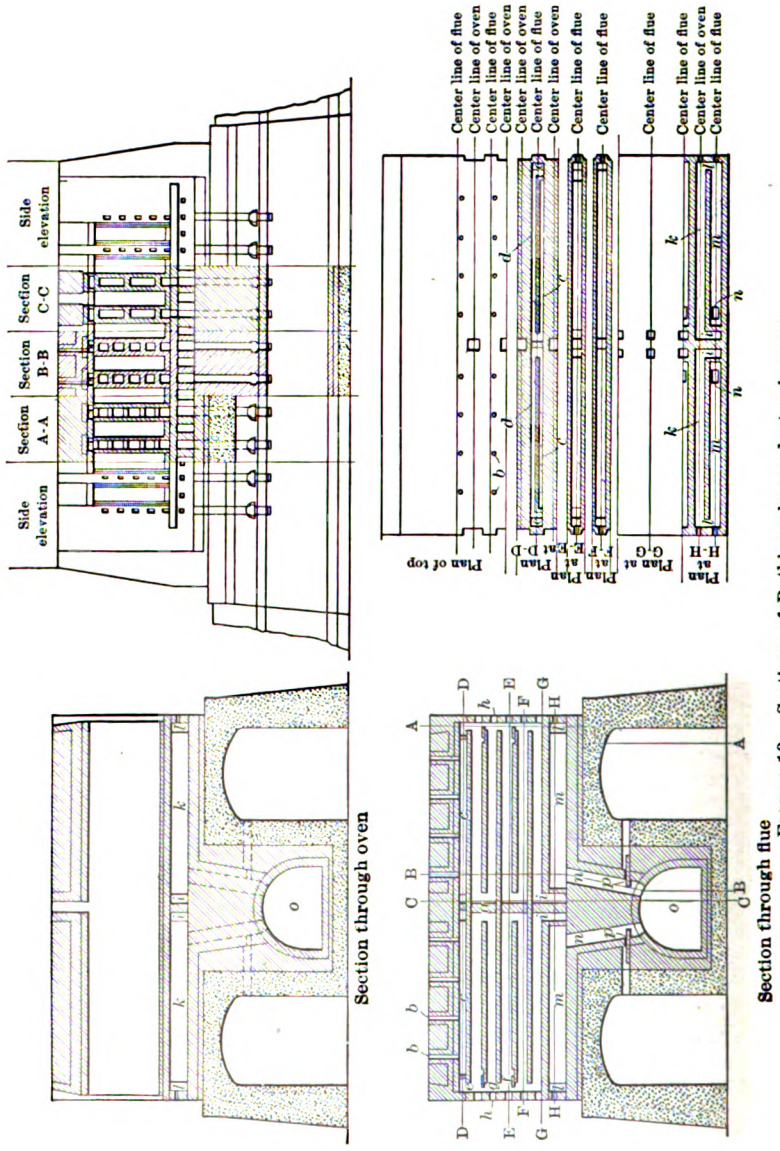

FIGURE 13.—Sections of Rothberg by-product coke oven.

of fire brick, a number of such retorts being placed side by side to form a battery. The dimensions in different installations vary somewhat, but in general the ovens are about 33 feet long, 6½ feet high, and from 17 to 22 inches wide. The width of the retort gen-

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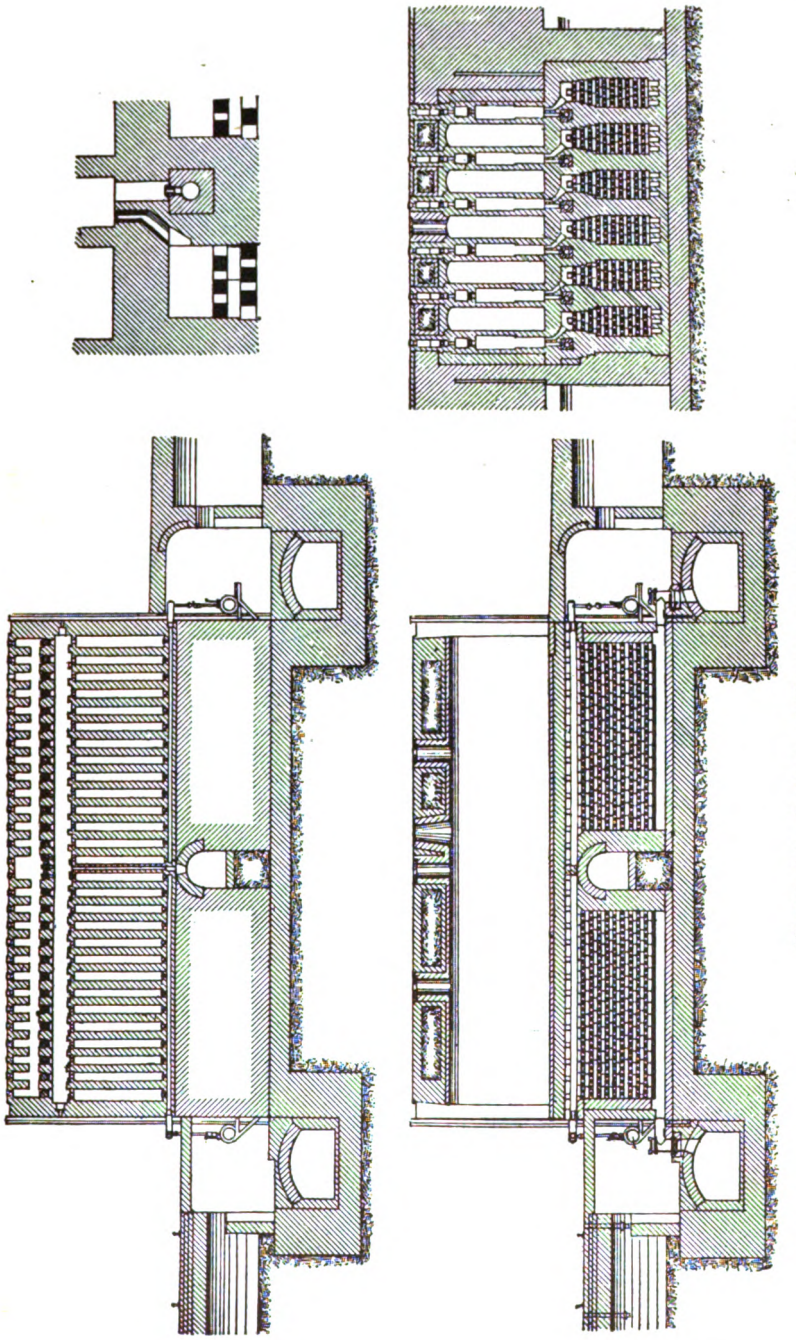

FIGURE 14.—Sections of Koppers by-product coke oven.

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erally tapers, the retort usually being wider at the discharge end. The amount of taper varies with the nature of the coal used—from 4 inches for coals that swell to 1 inch or even none for coals that shrink. The walls are provided with vertical or horizontal internal flues heated by gas.

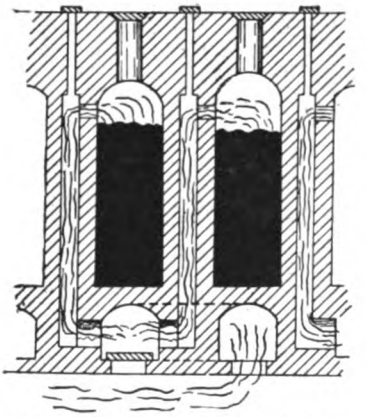

FIGURE 15.—Original type Coppée vertical-flue oven.

The ends of the retorts are closed by iron doors lined with fire brick. These doors fit closely and are luted with clay. The tops of the retorts are fitted with trunnel heads through which the coal is charged and uptake pipes through which the evolved gas passes to the gas collecting mains along the top of the battery. The ovens are leveled and drawn by means of mechanical devices, one type of which is shown in figure 17. The coke is watered outside the oven, sometimes in a closed receptacle, which causes the coke to retain its silvery appearance, but more often as the coke is pushed from the oven into the car (fig. 18) or onto the wharf in the air, which blackens the coke. The blackening of coke, due to watering in the air, has caused much of the prejudice against by-product coke, a prejudice that was especially strong at the time that by-product coke was first introduced into this

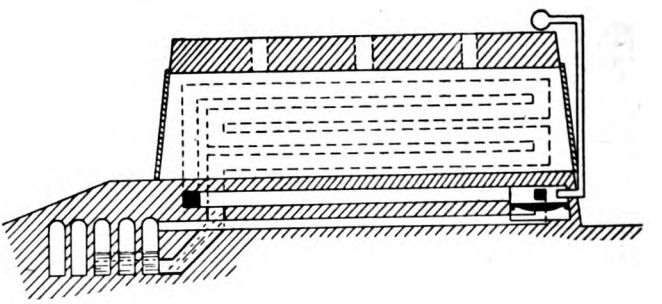

FIGURE 16.—Original type Simon-Carves horizontal-flue oven.

country, when furnace coke was judged mostly by sight. Fortunately, the metallurgical practices of the country are now more scientifically conducted and the chemical and physical characteristics of coke count for more than its mere appearance. By-product coke is now judged by men not prejudiced in favor of the beehive product.

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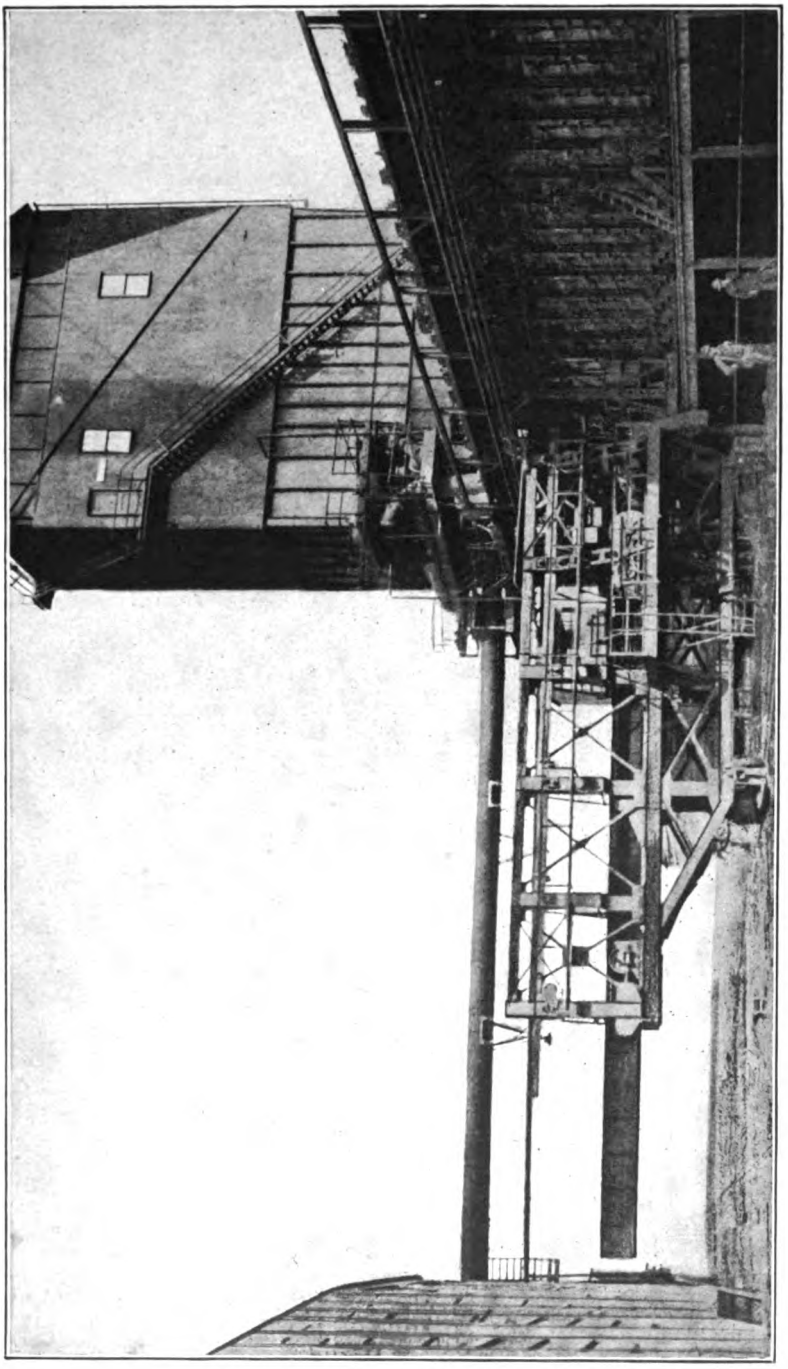

FIGURE 17.—Leveling and pushing machine for by-product coke ovens.

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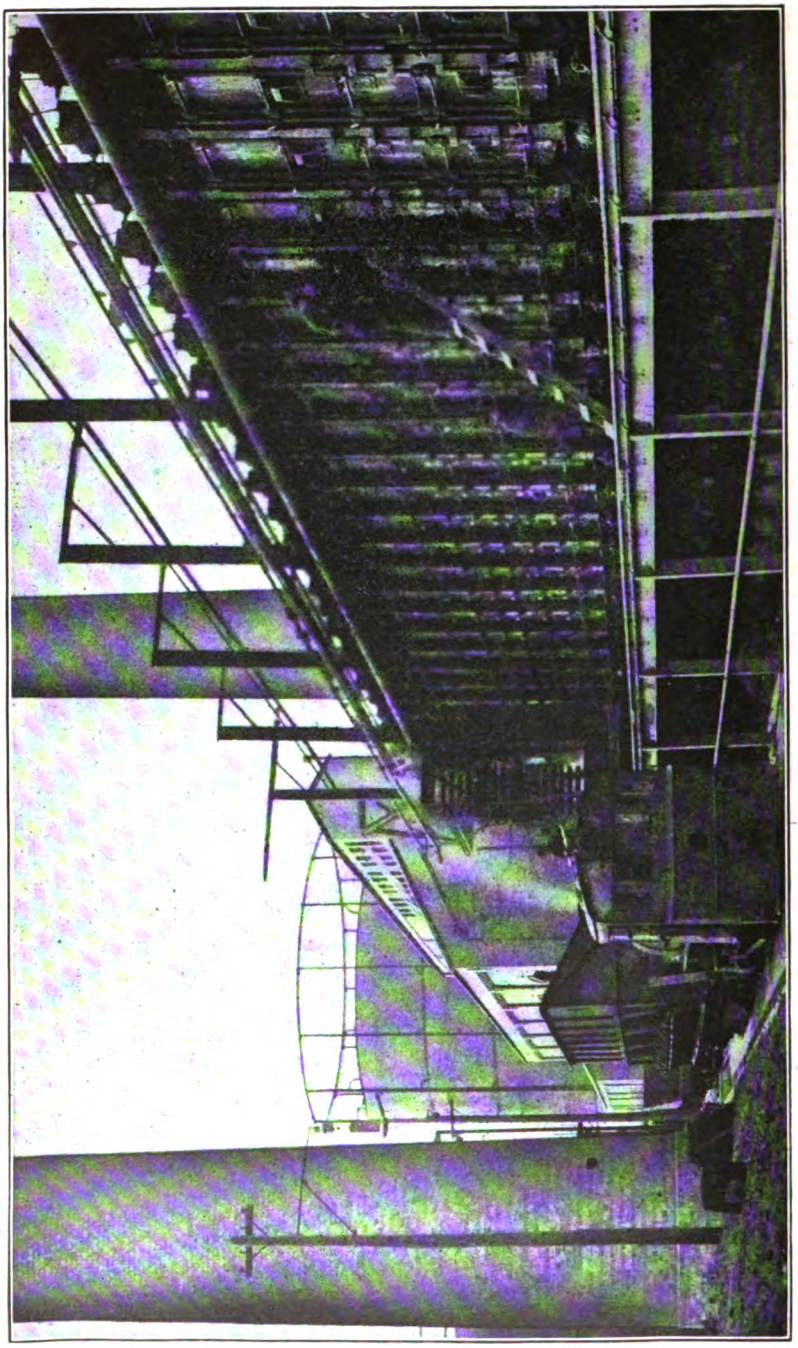

FIGURE 18.—Quenching of by-product coke in car.

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COKING IN BY-PRODUCT OVENS.

In by-product ovens a true distillation of the coal takes place. The whole process is under control and can be regulated. Heat is supplied by burning the gas from the coal in flues surrounding the oven. This gas is burned with a proper supply of air, with or without regeneration. The use of regenerators or other means of preheating is determined by the demand for the surplus gas for other purposes. Where regenerators are used the surplus gas amounts to 40 to 60 per cent of the total gas evolved from the coal. Uniformity of heating is the main desideratum, and the different builders of ovens with vertical or with longitudinal flues all claim to obtain uniform heating by their particular methods of regulating the burning of the gas. Uniform heating produces uniform coke

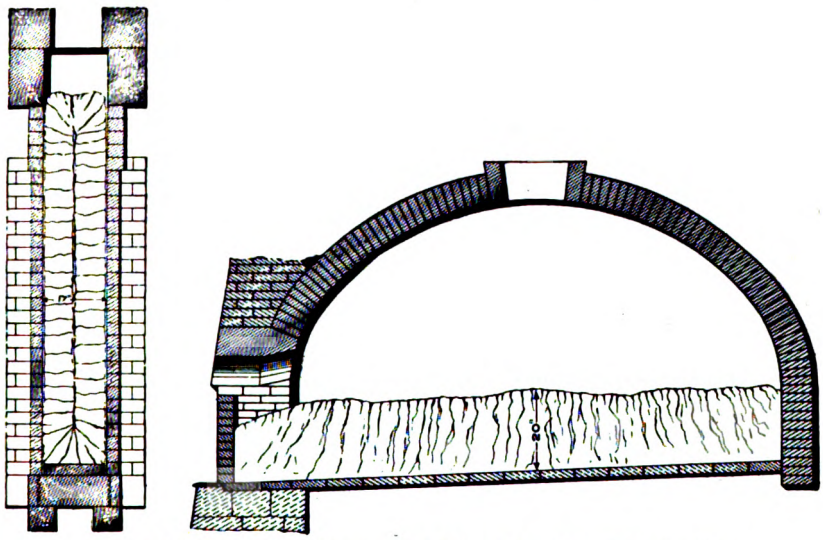

FIGURE 19.—Structure of by-product (*a*) and beehive oven coke (*b*).

throughout the charge and reduces the time of burning. Uneven heating causes the coal at the points of higher heat to coke more rapidly, thus making a nonuniform product, and lengthens the time required for proper burning, thus reducing the total output of the oven per unit of time if not the actual yield of coke from the coal. Coking proceeds from the sides of the oven to the middle; and if the process is properly handled, a marked line of cleavage is produced down the center of the whole charge. The width of the oven, from 17 to 21 inches, gives to the coke produced in a by-product oven a short, blocky structure, as distinguished from the long columnar structure of coke from the beehive oven, in which coking proceeds from the top downward (fig. 19).

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Since no fixed carbon is burned during the process of by-product coking, and since in this process conditions are more favorable for the breaking up of the heavier hydrocarbons, with subsequent deposition of carbon on and through the coke, the yield from any coal in by-product ovens is higher than the yield from the same coal in beehive ovens. The percentage of impurities is reduced in proportion to the increased yield. Statistics collected by the United States Geological Survey [a] give the average yield of by-product ovens as 75.1 per cent, compared with 64.7 per cent for beehive ovens.

YIELD OF BY-PRODUCTS.

The yield of by-products is dependent on the working of the oven and can be regulated within certain limits at the option of the operator. The quality of the coke can be sacrificed for a better quality and increased yield of gas and by-products, or the latter can be sacrificed somewhat for better coke. The manipulation of the ovens depends in large degree upon which product is the more desired. Ideal conditions are reached when a coke possessing the chemical and physical properties necessary for the purpose for which it is intended is produced, together with a maximum yield and quality of by-products.

If surplus gas is used for fuel purposes alone, only one gas main from the top of the ovens is necessary; if the surplus gas is used for illuminating purposes as well, two mains are installed—one to take off the rich gas evolved during the first period of coking, and the other to take off the poorer, or fuel gas. The evolution of gas for illuminating purposes varies in practice according to the candlepower demanded. Roughly speaking, the first half of the gas is used, or that which is given off in 6 to 10 hours, depending on the length of the coking time. The two gases are kept separate throughout the whole operation, so that two sets of apparatus, usually in parallel, are necessary.

The illuminating gas, after passing through the cooling, condensing, and other necessary devices, is enriched by the addition of benzol and piped to the gas holder. The fuel gas, after being separated from its by-products, is used for heating the ovens and for other fuel purposes. The travel of the gas from the ovens through the different stages of the process in which the by-products are removed differs considerably, depending upon the methods used and the extent to which the by-products are utilized, but in general is as follows:

[a] Parker, E. W., Coke: Mineral Resources U. S. for 1911. U. S. Geol. Survey, 1912, pt. 2, p. 230.

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From the ovens the gas passes through the uptake pipes to the gas main along the top of the ovens and then through the air coolers, water coolers, scrubber, exhauster, tar extractor, and ammonia washers to the gas holder. The ammoniacal liquor from the ammonia washers is distilled and the ammonia (NH_3) is passed into sulphuric acid to form ammonium sulphate (fig. 20), or into a condenser and saturator to form strong ammonia liquor varying in NH_3 content, but usually containing between 15 to 20 per cent. In the event of rich gas being used for illuminating purposes the poor gas is passed through benzol scrubbers before reaching the gas holder, and the benzol thus extracted is added to the rich gas. The direct process for the recovery of ammonium sulphate (fig. 21), which has come into wide use, dispenses with ammonia washers, the gas, after the removal of the tar, being passed through a reheater and thence directly into the sulphuric acid. The recovery of benzol for purposes other than enrichment, as well as of light oil, is carried on to some extent in this country; further than this, the recovery of by-products is little practiced, by-products being obtained by distillation of the tar extract.

PREPARATION OF COAL FOR COKING.

The large increase in the demand for coke and the wide area over which this demand is spread have made it necessary to find coal for coking in coal beds other than those that yield coals producing coke without preliminary treatment. There is, comparatively speaking, little coal from which a metallurgical fuel of proper physical characteristics and chemical purity can be obtained without preliminary treatment, and this amount is becoming less each year. Connellsville coal, which stands preeminent as the producer of the finest metallurgical coke, practically prepares itself. Owing to the softness and columnar structure of Connellsville coal, it breaks fine in mining and is further reduced in size by subsequent handling, so that the coal reaches the oven in comparatively small pieces of uniform size. Because of this fact, and also because Connellsville coal is free from impurities, preliminary treatment is unnecessary. With most other coals experiments to determine the impurities must be made with a view to removing the impurities by different methods, which depend on the kinds of impurities and the way in which they are combined. In many cases the simple expedient of fine crushing answers the purpose by making distribution of the impurities uniform. The picking table and the Bradford breaker are simple devices, but in general the impurities are of such nature that the coal has to be washed.[a] It is not

[a] For a detailed statement of washing tests of coals from many coal fields, the reader is referred to U. S. Geol. Survey Bulls. 336 and 368, and Bull. 5, Bureau of Mines.

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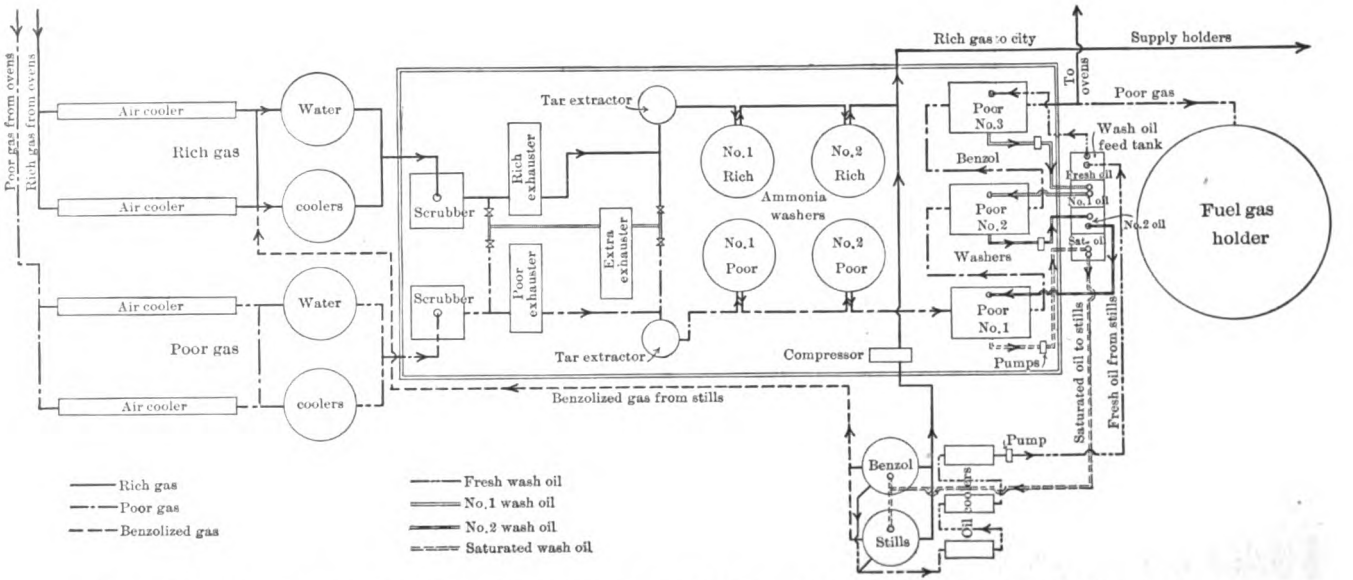

FIGURE 20.—Plan view of indirect process for recovery of ammonium sulphate and benzol enrichment of illuminating gas.

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the purpose of this paper to discuss washing methods or to give detailed descriptions of the many different designs of jigs now in successful operation in this country. It is perhaps only necessary to say that the removal of impurities by washing is in all cases dependent on the difference in specific gravity between the coal and the impurities. The impurities, being heavier than the coal, are caused to settle to the bottom by the jigging or pulsating of the water and are drawn off; the coal floats on top and is carried off to the bins, where good coal is kept.

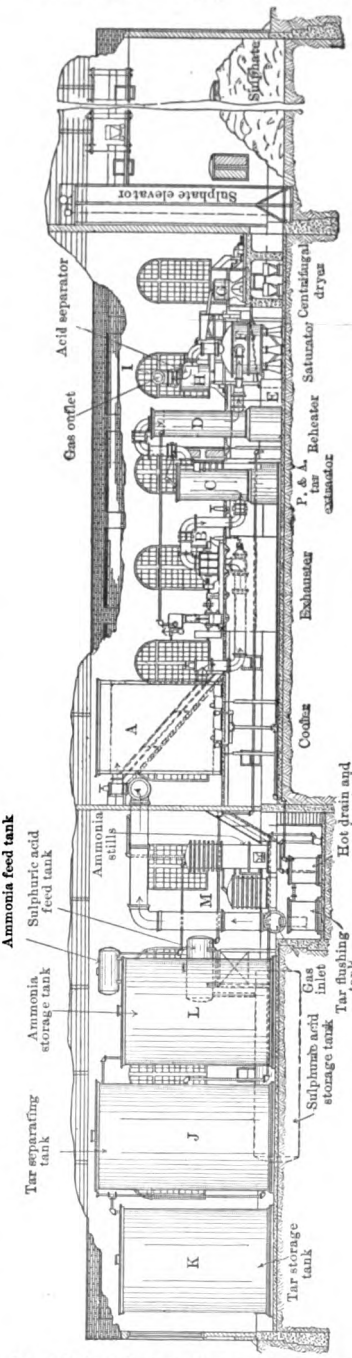

FIGURE 21.—Diagrammatic view of direct process for recovery of ammonium sulphate.

IMPURITIES IN COAL.

SULPHUR.

The impurities in coal are mainly sulphur, phosphorus, and ash. The sulphur is principally in two forms, iron sulphide (FeS_2), either as iron pyrites or marcasite; and sulphate of lime, or gypsum. Sulphur in the form of sulphide can be more or less completely eliminated in the coking process, but the sulphate in the coal remains in the coke. The proportion of sulphur eliminated varies in different coals and also in different ovens burning the same coal. The average loss of sulphur in the beehive oven for all coals in the country, as shown by the results of the tests made by the technologic branch of the United States Geological Survey,[a] which had charge of the fuel technology investigations

[a] Moldenke, Richard, Belden, A. W., and Delamater, G. R., Washing and coking tests of coal and cupola tests of coke, conducted by the United States fuel-testing plant at St. Louis, Mo., January 1, 1905, to June 30, 1907; U. S. Geol. Survey Bull. 336, 1908, p. 47.

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now conducted by the Bureau of Mines, is 43.27 per cent of that contained in the coal. Results of tests made in by-product ovens because of the higher yield of coke show a somewhat larger percentage of sulphur eliminated. The elimination of sulphur may be represented by the following formula:

$$\frac{a-(b\times c)}{a}=x.$$

Where a = percentage of sulphur in coal, b = percentage of sulphur in coke, c = percentage of good coke yielded by coal (not total yield), and x = percentage of sulphur eliminated. To obtain the total decrease of sulphur during the coking process the same formula can be used, but in this case a = percentage of sulphur in coal, b = percentage of sulphur in product (coke, breeze, and ashes), c = total percentage of yield (coke, breeze, and ashes) by coal, and x = percentage of sulphur eliminated.

Numerous methods for the elimination of sulphur during the coking process have been suggested and attempted, but none of them has shown material reduction of the sulphur content of the coke.

PHOSPHORUS.

The phosphorus in the coal is retained in the coke. The percentage of phosphorus in the coke may be closely approximated by dividing the percentage of phosphorus in the coal by the percentage expressing the theoretical yield of coke. For metallurgical operations requiring a certain minimum percentage of phosphorus, careful selection of the coal or a preliminary washing to reduce the phosphorus are the only means of obtaining the desired results.

ASH.

All the ash of the coal is found in the coke, and where the coal as found is not low enough in ash to produce coke of a desired ash content a preliminary treatment must be used. In general it may be said that the percentage of ash in the coke is equal to the percentage of ash in the coal divided by the sum of the percentages of ash and fixed carbon.

EFFECT OF CRUSHING COAL BEFORE COKING.

Generally speaking, crushing a coal before it is charged into ovens, whether it has received other preliminary treatment or not, improves the quality of the coke produced. By crushing, a more uniform mixture of the coal is obtained and the ash and other impurities that occur in different layers of the coal bed are evenly distributed throughout the charge. The subsequent breakage of the coke due to

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unevenly sized slate is reduced, the breakage is along natural lines of cleavage, and the coke is drawn in larger sizes. The proportion of breeze is reduced through the elimination of large pieces of slate, because these break away from the coke on drawing or subsequent handling. The coke cells are closed and the coke is stronger and better able to carry its burden in the cupola or furnace. In the Rocky Mountain region it is absolutely necessary to crush finely all coal, whether it receives other preliminary treatment or not, in order to obtain coke that will withstand the blast in the iron or smelter furnace. Fine crushing increases the percentage of ash in the coke, because the "slate" is intimately mixed and does not fall away on handling. This fact was demonstrated at a commercial plant where an experiment of fine crushing was tried. The coke from finely crushed coal was found to be stronger and more dense and promised better results in the blast furnace than coke from run-of-mine coal. To the surprise of those in charge of the experiment it was found that about 300 pounds more of this coke were needed to produce a ton of iron. Investigation demonstrated that the coke from the finely crushed coal contained 2 to 3 per cent more ash than that from the run-of-mine coal. With the Rocky Mountain coal it would have been necessary to accept this increase of ash in the coke or to resort to some form of preliminary treatment to reduce the ash content of the coal, because the coke from uncrushed coal was not strong enough to stand the blast and to carry the burden.

It has been thoroughly demonstrated that coals which produce no coke if charged into the oven in the condition in which they are mined produce coke if finely crushed before charging. In many instances coke made from uncrushed coal, and having the characteristics of good coke, such as silvery-gray color, much deposited carbon, metallic ring and good breakage, and a low percentage of impurities, will not do the work that one would expect from its appearance, but if the simple expedient of fine crushing before coking is adopted coke from the same coal will fill all requirements. Though the writer is not prepared at this time to give the reasons for the facts stated above, or to make scientific deductions therefrom, the fact remains that fine crushing of coal before coking undoubtedly does produce the effects described.

MIXING OF COALS.

The necessity of producing a metallurgical coke that will meet the exacting demands of the modern blast furnace and the fact that the available supply of good coking coal for this purpose is rapidly diminishing have made a study of the future supply imperative. As a result of this study it is generally believed at present that

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little, if any, of the available coal is suited for the production of coke in either the beehive or by-product oven without preliminary treatment. Coking in the beehive oven is limited to certain coals that produce coke naturally, and therefore the country must look for its future supply to the by-product oven, in which coke of desired chemical and physical properties can be produced by proper mixing of coals. The best results seem to be obtained when coals are mixed in proportions that give about 25 per cent volatile matter in the mixture, and this practice is generally followed throughout the country wherever mixed coals are used.

YIELD OF COKE.

By the term "yield," as it is generally used, is meant the percentage by weight of the constituents of the coal left as coke after the process of coking is completed. Distinction should be made between yield of coke and total yield, the latter being the percentage by weight of the constituents of the coal left as coke, breeze, and ashes.

DETERMINATION OF YIELD.

The tendency of some authors to figure yield of coke from coal, or the increase or loss of a certain constituent of the coal from the chemical analysis, is to be regretted. The determination of the volatile matter of coal, even according to the official method, is at best only approximate, and conditions in the coke oven, even in retorts where the temperatures are controllable, do not correspond with those of any method used in the laboratory.

Until a laboratory method for the determination of volatile matter has been perfected so as to give results corresponding to those obtained in the oven and the causes of variation between the two are determined it will hardly be possible to predict the yield of coke from the chemical composition of the coal. The total yield of some coals, even in beehive ovens, where some fixed carbon is necessarily burned to complete the process, is greater, as shown by actual figures taken from accurate weighings of the coal, coke, breeze, and ashes, than the yield calculated from the official or other laboratory method. That the carbon from the volatile matter of the coal is deposited on the coke by the breaking up of the heavier hydrocarbons formed at relatively low temperatures is certain, but it hardly seems possible that the silvery deposit seen on the outside of beehive coke can fully account for the carbon burned plus the excess yield above the theoretical yield. Further chemical and microscopical study may warrant the conclusion that a large amount of the volatile matter is deposited as carbon through as well as on the coke and is even con-

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verted into solid carbon so intermixed with the coke proper as to be indistinguishable. There is a strong probability, supported by the experimental data obtained thus far in laboratory studies of coal, that fixed carbon, tar, and gas do not exist as such in coal at all, but that the compounds which make up the entire substance of coal dissociate under the influence of heat and give the above-named products. The manner in which the compounds break down and the relative proportion of any product—for example, fixed carbon or coke—depend upon the rate and intensity of the heating.

It has been shown, both by theoretical reasoning and by practical experience, that the yield of coke from coal can not be determined from chemical analyses, and that the only method of obtaining the true yield by any method of coking is to take the average actually obtained from a large number of coking operations.

PHYSICAL PROPERTIES AND CHEMICAL COMPOSITION OF COKE.

Coke varies greatly in its external appearance, physical properties, and chemical composition. In external appearance it may be dull gray, light gray, light gray and silvery, or, as generally expressed, "of metallic luster" when coated with deposited carbon, or black; occasionally it is iridescent. It generally has a rough surface, but that part of the charge near the walls of the oven is often smooth and glassy. Sometimes hairlike threads are observed on the surface of ordinary coke. This "coke-hair," like the "metallic luster," is due to deposition of carbon from the heavier hydrocarbons given off at lower temperatures. The process of deposition is described by Percy[a] as follows:

> A bubble of tarry or hydrocarbon vapor and gas, in escaping from the surface of the coke, becomes more highly heated, and is in consequence decomposed with the separation of solid carbon, which is deposited as a continuous coherent film on the surface of the bubble; a second bubble escapes through the carbonaceous shell of the first and is similarly decomposed, forming a second carbonaceous shell attached to that resulting from the first bubble; and so on by succession of such deposits of carbon a continuous tube is formed. Gas would continue to flow through this tube, depositing carbon in its course on the inner surface, until at length the tube is converted into a nearly solid fiber.

COLOR.

The color of coke may be due to the nature of the coal from which it is made, to the temperature during the coking process and the time of its application, to watering the coke, whether inside or outside the oven or in an open or closed receptacle, and perhaps to other factors. The watering of by-product coke on the wharves or in different style

[a] Percy, John, Metallurgy; Fuel.

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cars, exposed to the air during quenching, blackens the coke and adds an excessive amount of water. Where by-product coke is watered in closed receptacles the silvery gray color is preserved and the percentage of water is comparable with that in the beehive product. The color of coke, however, is by no means a safe criterion of its adaptability to the work to be done. The trouble formerly experienced by by-product coke makers in getting a trial for their product in the blast furnaces of this country is an illustration of the suspicion in which by-product coke was held. The coke was condemned without trial because of its dark, dull, dirty appearance. Subsequent experience has disproved the old idea that beehive coke is the best metallurgical fuel.

PHYSICAL STRUCTURE.

In physical structure coke may be porous and light, or dense and heavy; it may be soft or hard and capable of sustaining heavy load and not easily crushed in metallurgical operations or in transportation, or it may be brittle, whether hard or soft, with a tendency to break up easily into small pieces. When sharply struck it gives a clear, ringing sound, in some specimens almost like tempered steel, or, if soft and punky, it gives a dull, heavy sound. The ease with which coke ignites and enters into combustion also varies greatly.

The terms light and heavy refer to the specific weight of the coke. Dense is opposed to porous. The less the cell space the more dense is the coke and the greater the cell space the more porous is the coke. The size of cells does not determine the porosity of the coke; thus, visual examination of a coke may show that it possesses small cells, while determination of the percentage of cells by volume will show that the cell space is exceedingly large; in like manner, the cell structure of a coke may be large but the percentage of cells by volume may be small. The terms dense and hard, soft and porous, must not be confused; hardness and softness refer to strength of the cell walls of the coke, density and porosity to cell space. Generally speaking, dense cokes are also soft and punky, and porous cokes, unless the cells be unduly enlarged, are hard. This, however, does not always follow. Some of the best cokes, capable of withstanding the work of any modern metallurgical operation, are dense and hard, and in some processes, especially where permeation of gases is not a chief factor, density combined with strength is a desideratum.

Numerous experiments as to the relative value of charcoal, anthracite, and coke have demonstrated that it is this cellular structure which gives to coke its great advantage as a metallurgical fuel, and for this reason it may be stated that within certain limits, other things being equal, the more porous the coke the better it is as fuel. There is, of course, a limit to the advantage gained by this porosity,

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and this limit is reached when the cells are developed to such an extent that the cell walls are weakened, so that coke crushes in the furnace. A further increase in the size of the pores is, of course, injurious. The porosity of coke depends on the nature of coal from which it is made, the washing of the coal, the fineness of crushing, the tamping and compacting in charging, the process of making, the kind of oven used, the depth of charge, the temperature of coking, and the length of time applied. There may be other factors, but the foregoing are, in the main, the controlling or determining ones.

POROSITY.

All coke is more or less porous. In some instances cells may be entirely inclosed, not communicating with other cells, but generally coke is permeated by a complicated system of intercommunicating pores.

SPECIFIC GRAVITY.

The determination of the real specific gravity, or the specific gravity of the coke substance, is made on a finely ground sample by the usual methods.[a]

APPARENT SPECIFIC GRAVITY.

DETERMINATION.

The apparent specific gravity, or the relation between the whole mass of material and an equal volume of water, is generally determined on 1-inch cubes as first suggested by Hunt[b] and later improved by Dewey.[c] Dewey selected representative specimens weighing from 20 to 40 grams, dried them at 100° C., and determined the weight of the dry coke. He soaked these samples in water from 12 to 24 hours, then placed them under the receiver of an air pump and exhausted the air as completely as possible; this operation he repeated several times in order to insure replacement of air by water. The thoroughly saturated specimens were weighed first in water and then in air and calculation made as follows: The loss in weight in water of the saturated material, less the weight of water absorbed, divided by the weight of the dry material, gives the apparent specific gravity. The many objections raised to this method, due to the difficulty of preparing 1-inch cubes, the uncertainty in completely filling the pores and in subsequently drying the exterior without abstracting water from the pores, and the loss of weight during

[a] See Technical Paper 8, Bureau of Mines, p. 16.

[b] Hunt, T. S., The porosity of rocks: Report of the Geological Survey of Canada, 1863–66, pp. 281–283.

[c] Dewey, F. P., Porosity and specific gravity of coke: Trans. Am. Inst. Min. Eng., vol. 12, 1883–84, p. 111.

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weighing, due to evaporation of water, led to the development of a method by the chemical laboratory of the Bureau of Mines as outlined below.[a] The special apparatus is shown in figure 22. This apparatus is so calibrated that 500 grams will sink it in the water to the middle of the spindle just above the float. Pieces of coke 2½ to 3 inches in diameter are placed on the large pan, a small piece or two being added, if necessary, to bring the water to the right mark. The apparatus is then taken out of the water and the coke is transferred from the pan to the basket, then immersed again, and weights are placed on the small pan until the water again reaches the mark. The weight of the sample in air divided by the loss of weight of the sample in water gives the apparent specific gravity.

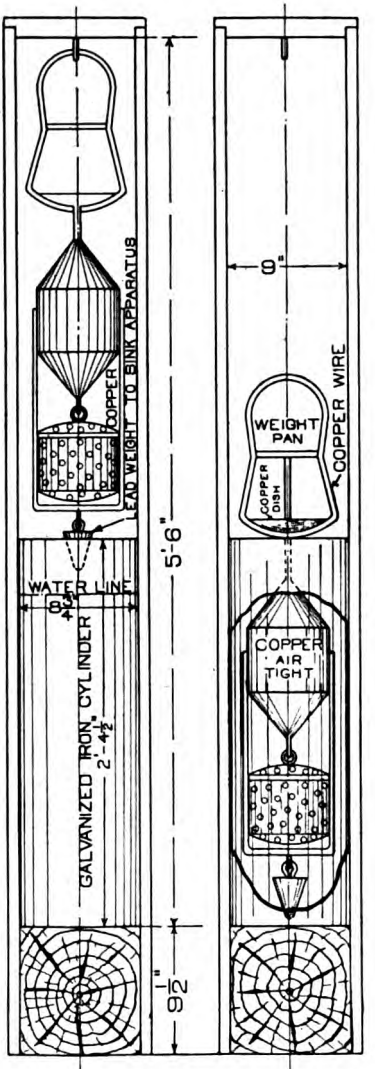

FIG. 22.—Apparent specific-gravity apparatus.

PERCENTAGE OF COKE SUBSTANCE.

The percentage of coke substance by volume is determined by dividing the apparent specific gravity by the real specific gravity.

PERCENTAGE OF CELLS BY VOLUME.

The percentage of cells by volume is determined by subtracting the apparent specific gravity from the real specific gravity and dividing the difference by the real specific gravity.

VOLUME OF CELLS IN 100 PARTS BY WEIGHT.

The volume of cells in 100 parts by weight is obtained by dividing the percentage of cells by volume by the apparent specific gravity.

For a description of the methods used by the Bureau of Mines in analyzing coke and determining its heating value the reader is referred to Technical Paper 8.[b]

[a] See Technical Paper 8, Bureau of Mines, p. 17.

[b] Stanton, F. M., and Fieldner, A. C., Methods of analyzing coal and coke: Technical Paper 8, Bureau of Mines, 1912, 21 pp., 5 figs.

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SIZE.

Modern practice no longer demands coke in large, long pieces, but coke of a uniform size. The action of blast furnaces and cupolas is more regular and uniform if coke of uniform size is used. The author has been unable to ascertain whether any furnace plant in this or any other country reduces coke to uniform size by crushing, but he is inclined to believe that, in spite of the added cost and attendant loss due to fine coke, crushing would still prove economical by reason of the better working of the furnace, the prevention of slips and scaffolds, and the uniformity of the metal produced. The size to which coke should be crushed is a matter for determination by experiment.

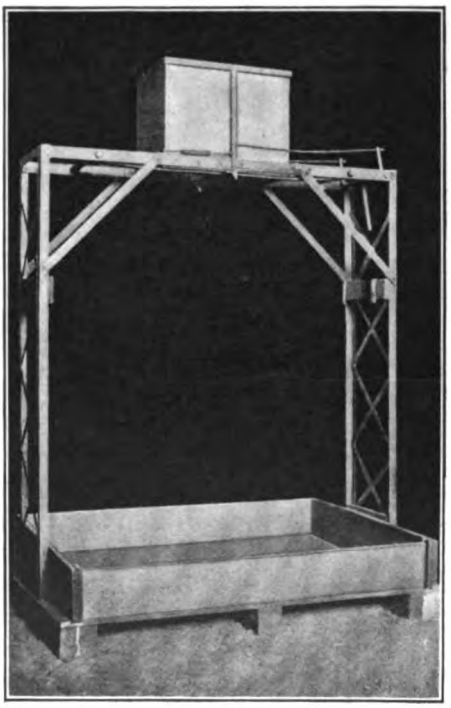

FIGURE 23.—Coke shatter-test apparatus.

SHATTER TEST.

The relative breakage of all cokes made in the investigations conducted by the Bureau of Mines is determined by the shatter test. This test, which can be varied to suit individual requirements, consists in dropping a definite weight of coke on an iron plate from a height of 6 feet. The number of times dropped, whether the coke should be screened between successive drops, and other factors can be varied to suit individual needs. The Bureau of Mines, in order to make all its tests comparable, has adopted the following apparatus and method:

APPARATUS AND METHOD.

The apparatus for making the test as shown in figure 23 consists of a supported box capable of holding 100 pounds of coke, the bottom of the box being 6 feet above a cast-iron plate. The doors on the bottom are so hinged and latched that they will swing freely when opened and will not impede the fall of the coke. Boards about 8 inches high are placed around the iron plate so that no coke may be lost. With a coke fork a sample of approximately 50 pounds is placed in the box, no attempt being made to arrange it therein. The

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entire contents of the box is dropped four times on the iron plate, the small material and the dust being returned each time with the large coke. After the fourth drop the material is screened on a screen of 2-inch mesh; the coke that remains on the screen and what passes through are weighed and the breakage is determined. If the sum of the weights indicates a loss of over 1 per cent the test is rejected and a new one made.

COMPRESSIVE STRENGTH.

The question of obtaining the true compressive strength of coke by means of 1-inch cubes has received much attention from various investigators. The comparison between cokes made from the same coal in different types of ovens, or even in ovens of the same plant, or the comparison of cokes in general by means of the results of compressive strength tests is difficult if not impossible. The inability to select a cube, or any number of cubes, to represent anything more than the piece from which it is taken has been demonstrated by the experiments conducted by the Government.[a] About 800 cubes taken from 174 tests of 94 coals from all sections of the country, representing as nearly as possible comparable and representative samples of the different cokes and those from the same portion of the oven, were tested for compressive strength. The variations in the results, even in cubes of the same coke from one oven, to say nothing of cubes from different ovens, were in all instances so great as to preclude the drawing of any conclusion other than the worthlessness of attempting such comparison. Other cubes were selected that represented each inch of the whole height of the coke in the oven and an attempt was made to obtain an average from the compressive strength of the individual pieces. Results from this procedure were also shown to represent nothing but the piece of coke from which the cubes were cut. Similar cubes from pieces on either side of the first, as well as from different parts of the oven, showed no uniformity either individually or on an average. The condition and the burning of the oven, the quenching either inside or out, and any number of factors of which we have no knowledge and can not control cause great variation in the coke from different parts of the same oven. The prime consideration is the probable breakage of the coke during its descent in the furnace or cupola, where many other factors than compressive strength have to be considered, such as the action of gases and high temperatures, and the attrition of coke against coke and other constituents of the burden and against the walls of the furnace. The breakage of the best coke on handling and in transportation is a con-

[a] Moldenke, Richard, Belden, A. W., and Delamater, G. R., Washing and coking tests of coal and cupola tests of coke, conducted by the United States fuel-testing plant at St. Louis, Mo., June 1, 1905, to June 30, 1907: U. S. Geol. Survey Bull. 336, 1908, p. 45.

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siderable item, and in cokes of poorer quality the importance of this item increases in proportion as the friability increases.

Attempts have been made to use the compressive strength of a coke for calculating the height of furnace burden that the coke is capable of sustaining. This practice is not warranted, as the following simple statement will show:

1 cubic foot of coke weighs approximately 28 pounds, 1 cubic foot of ore and flux weighs approximately 115 pounds.

If the charge is mixed in the approximate proportion of 3 parts by weight of ore and flux to 1 part by weight of coke, then

28 pounds coke	=1.00 cu. ft.
86 pounds ore and flux	=0.75 cu. ft.
114 pounds charge	=1.75 cu. ft.

One cubic foot of charge therefore weighs 65 pounds. Let it be assumed that the weight of the charge is evenly borne and that the height of the furnace is 95 feet, then the weight on each square foot at the base is 65 multiplied by 95, or 6,175 pounds per square foot, or about 43 pounds per square inch. Even the poorest cokes would doubtless show a crushing strength much in excess of this figure.

BEEHIVE COKING IN THE UNITED STATES.

Beehive coke is produced in the fields of five of the six great coal provinces of the United States, as follows: The Appalachian region of the eastern province, in the fields of Pennsylvania, Virginia, West Virginia, Ohio, Tennessee, Georgia, Alabama, and eastern Kentucky; the eastern region, from fields in Illinois, Indiana, and western Kentucky, and the western region, from fields in Kansas, Missouri, and Oklahoma, of the interior province; the Rocky Mountain province, from fields in Colorado, Montana, Utah, and New Mexico; and the Pacific coast province, from fields in Washington.

COKE FROM NORTHERN PART OF APPALACHIAN FIELD.

PENNSYLVANIA COKE.

Pennsylvania has from the beginning of coke making in the United States maintained the supremacy in production. The beehive-oven coke from the Connellsville district is still considered the standard coke of the country, cokes from all other sections of the country being judged by comparison with it. The coal from the Connellsville district contains approximately 31 per cent of volatile matter, the proportion and composition of which seem to favor its distillation in the beehive oven at a temperature and rate that favor a maximum yield of coke with a minimum loss of fixed carbon. Practically all the coal in this district is mined for the production of coke and is

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charged into the ovens without any special preparation. About 14 per cent of the coal from other coking regions of the State is washed before coking, and the coke produced is of varying purity and physical structure. The range of composition of the Pennsylvania coke is as follows:

Range of composition of Pennsylvania coke.

	Per cent.
Moisture	0.23 to 0.91
Volatile matter	.29 to 2.26
Fixed carbon	92.53 to 80.84
Ash	6.95 to 15.99
Sulphur	.81 to 1.87

WEST VIRGINIA COKE.

Much West Virginia coal is exceptionally pure, and the coking industry in this State, although ranking second in production, is mainly incidental to furnishing steam and domestic coal. More than 60 per cent of the coal charged into the beehive ovens is slack and less than 10 per cent of it is washed. At those plants where proper attention is given to preparation of the coal and the operation of the ovens themselves, a coke of superior chemical and physical properties is produced. The quality of the larger part of the West Virginia cokes is exceptionally good, but there is still a wide variation in their chemical composition, as the following table shows:

Range of composition of West Virginia coke.

	Per cent.
Moisture	0.07 to 0.60
Volatile matter	.46 to 2.35
Fixed carbon	95.47 to 84.09
Ash	4.00 to 12.96
Sulphur	.53 to 2.26

VIRGINIA COKE.

All the coke produced in Virginia is made from unwashed coal and is made in the southwestern part of the State. In chemical and physical properties it resembles the coke from southern West Virginia.

COKE FROM SOUTHERN PART OF APPALACHIAN FIELD.

The cokes from the southern part of the Appalachian region, comprising eastern Kentucky, and the States of Tennessee, Georgia, and Alabama, are for the most part made from washed coal. The coke is of poorer quality, and its ash and sulphur content are high. The average ash content is about 14 or 15 per cent, often running up to 16 and 18 per cent at plants where proper attention is not paid to

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preparation and coking. The Birmingham district of Alabama produces a fairly large amount of good beehive-oven coke having an ash content averaging 11 per cent, but such coke is the exception and not the rule.

Range of composition of coke from the southern part of the Appalachian field.

	Per cent.
Moisture	0.75 to 1.34
Volatile matter	.75 to 1.95
Fixed carbon	91.20 to 77.81
Ash	7.30 to 18.90
Sulphur	.58 to 1.77

COKE FROM EASTERN INTERIOR FIELD.

The manufacture of beehive-oven coke in the States of Illinois and Indiana is practically at a standstill. A few ovens for experimental purposes have been built and have demonstrated the practicability of producing coke from some of the coals in these States. The Illinois and Indiana coking coals are confined to small areas, and beehive ovens will hardly be established in these fields.

COKE FROM WESTERN INTERIOR FIELDS.

Kansas, Missouri, and Oklahoma have had poor success in the production of coke, and the total output from ovens in these States is small.

COKE FROM ROCKY MOUNTAIN FIELD.

Practically all the coke from the States of Colorado and New Mexico is made from coal that is washed and crushed before being charged into the ovens. A plant comprising 350 beehive ovens of concrete construction is one of the novelties of this region. The ovens proper are of the ordinary beehive type, 13 feet in diameter and 7½ feet high, constructed of fire brick and tile. The ring walls and wharf walls are of plain concrete, the battery walls and larry-track columns of reinforced concrete. The yield of coke is reported to be above the average for the region, and this increase is believed to be due in great measure to the concrete construction, which prevents the entrance of excess air through cracks, so common in ordinary beehive construction.[a] At another plant in this region the ovens are provided with underflues that convey the gases from the coal under the oven bottom to a large flue back of the ovens, which carries it to the power house. This power plant furnishes all the power for operation of the mines, for ventilation, electric haulage, coal washing and crushing, electric lights for the entire community, and in addition

[a] Lee, E. A., Mines and Minerals, February, 1910, p. 429, 432.

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supplies steam heat for the company buildings. The flues under the oven bottoms serve to hasten coking and to prevent black ends. Careful watching is required to prevent the coal from coking from the bottom as well as from the top. When the bottoms become too hot and the coal cokes upward as well as downward a distinct line of demarcation forms across the whole charge.

The cokes of these States are uniformly low in sulphur, rarely exceeding 0.75 per cent, but their ash content is high, averaging 16 per cent.

The coals used for manufacture of coke in Utah are practically identical in character with those of western Colorado, but exhibit the surprising characteristic of losing their coking properties and becoming noncoking if kept in storage for any great length of time.

Montana produces a very small amount of coke, all of which is used in copper smelters. The only restriction placed on the quality of the coke is that the ash content shall not exceed 20 per cent. This restriction is complied with only when the coal is washed. An average analysis of this coke shows 18 to 21 per cent ash and more than 2 per cent sulphur.

COKE FROM PACIFIC COAST FIELD.

Washington is the only State west of the Rocky Mountains that contains coking coal, and the area within the State is small. All the coke is made from washed and crushed coal and is of fairly good quality. An average analysis of this coke follows:

Average analysis of Washington coke.

	Per cent.
Moisture	0.92
Volatile matter	1.50
Fixed carbon	79.58
Ash	18.00
Sulphur	.52

BY-PRODUCT COKE OVENS IN THE UNITED STATES.

By-product coke is produced in 13 States as follows: Alabama, Illinois, Indiana, Maryland, Massachusetts, Michigan, Minnesota, New Jersey, New York, Ohio, Pennsylvania, West Virginia, and Wisconsin. On account of the necessity of disposing of the large amount of surplus gas, for which there is no outlet in coal-producing regions, together with the necessity, in most instances, of mixing coals to produce good metallurgical coke, the by-product plants are in the larger cities or are operated in connection with metallurgical plants. Table 4 gives some details regarding the by-product plants in operation in this country in 1912.

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TABLE 4.—*Details of by-product coke plants in the United States.*[a]

State.	Number of plants.	Number and kind of ovens.	Use of coke.	Use of surplus gas.	Analysis of coke (range).
					Per cent.
Alabama	4	280 Semet-Solvay, 340 Koppers.	Blast furnace	Fuel and power.	H_2O [b] 1.92–10.64 V. M. .95–1.58 F. C. 89.02–84.59 Ash 9.40–14.16 S. .71–1.08 P. .031–.071
Illinois	2	200 Semet-Solvay, 280 Koppers.	Blast furnace, foundry, and domestic.	Fuel, power, and illuminating.	H_2O [b] .73–7.00 V. M. .80–1.45 F. C. 89.84–87.00 Ash 8.63–11.55 S. .60–.83 P. .003–.015
Indiana	2	50 United Otto, 560 Koppers.	Blast furnace and foundry.	Fuel and illuminating.	
Maryland	1	200 United Otto	Blast furnace	Illuminating	H_2O [b] 8.00–11.00 V. M. 1.61–3.30 F. C. 86.99–85.73 Ash 9.75–12.12 S. 1.18–2.37 P. .004–.012
Massachusetts	1	400 Otto-Hoffman	Domestic, industrial, and locomotive.	do	
New Jersey	1	100 Otto-Hoffman, 50 United Otto.	Blast furnace, foundry, and domestic.	do	
Michigan	2	132 Semet-Solvay, 30 United Otto.	Furnace, foundry, domestic, and lime burning.	Fuel and illuminating.	H_2O [b] 1.80–2.64 V. M. .87–2.70 F. C. 91.93–87.98 Ash 7.20–9.70 S. .68–.97 P. .012–.01
Minnesota	1	50 United Otto	Blast furnace	Illuminating	
Wisconsin	1	160 Semet-Solvay	Blast furnace, foundry, and domestic.	Fuel and illuminating.	
New York	3	86 Semet-Solvay, 188 United Otto, 282 Rothberg.	Blast furnace, foundry, lime burning, and domestic.	do	H_2O [b] .58–5.50 V. M. 1.48–2.26 F. C. 89.49–79.95 Ash 8.48–16.26 S. .69–1.58 P. .010–.058
Ohio	2	50 Otto-Hoffman, 50 United Otto, 49 Semet-Solvay.	Blast furnace, foundry, and domestic.	Fuel, power, and illuminating.	H_2O [b] 1.35–3.00 V. M. .90–1.69 F. C. 88.10–87.35 Ash 8.75–10.92 S. .79–.95 P. .012–.035
West Virginia	1	120 Semet-Solvay	Blast furnace	Fuel	
Pennsylvania	7	360 Semet-Solvay, 404 Otto-Hoffman, 524 United Otto, 5 Rothberg.	Blast furnace and domestic.	Fuel, power, and illuminating.	H_2O [b] .20–11.00 V. M. .60–1.95 F. C. 89.68–84.65 Ash 9.52–13.40 S. .93–1.40 P. .011–.022

[a] This table, with exception of analyses, is from Manufacture of coke in 1911, by E. W. Parker, Mineral Resources U. S., 1911. U. S. Geol. Survey, 1912.
[b] Moisture separately determined.

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